The mediating & moderating influence of economic crises on the relationship between innovation effort and productivity

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Master thesis

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Abstract

The mediating and moderating influence of economic crises on the relationship between innovation effort and productivity is studied in this thesis, using 1990-2013 data from 117 countries. Among other things, it is found that economic crises are estimated to influence productivity negatively directly, because of resource misallocation, input underutilization, poor efficiency in financial intermediation and a fall in demand. It is also found that economic crises have a positive mediating impact on productivity, through innovation effort: the exertion of innovation effort is found to have a positive effect on the amount of value a firms adds to the value chain per unit of output and as a way to maximize capacity. Also, economic crises are found to have caused an increase in innovation effort. This is probably because there was a relatively high number of highly innovative firms during the researched economic crises, compared to during other economic crises, which are more able to not decrease their innovation effort during times of economic crisis and were rewarded in the form of highly increased productivity and survival odds. Also, firms might have increased their innovation effort because they already suspected the most important finding of this thesis: the relationship between innovation effort and productivity is estimated to be more positive in times of economic crisis. This is because in the struggle for survival during economic crises, every competitive advantage acquired through innovation, is expected to have an even larger reward than in times without economic crisis. Economic crises, therefore, turn out not to be bad exclusively: although firm productivity is estimated to decrease as a direct result of economic crises, the productivity reward of exerting innovation effort is found to be higher during an economic crisis than not during one.

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Introduction

In times of economic crisis, firms' focus changes from general long-term maximum profitability to preparation for and withstanding shocks, even survival: the focus changes to extremely short-term goals. For this reason, during times of economic crisis, less innovation is expected to take place in general; innovation effort is perceived as a cost, without a direct reward. The existing literature generally confirms this negative influence of economic crises on the exerted innovation effort (Archibugi, Filippetti & Frenz, 2013; Paunov, 2012; and Yunlu & Murphy, 2012) and even on investment in general (Arslan, Florackis & Ozkan, 2006; Campello, Giambona, Graham & Harvey, 2011 and Rockerbie, 1994).

This mechanism possibly changes other economic innovation relationships as well. In this study, a possible (temporary) change in the relationship between innovation and productivity during these periods of economic crises will be examined: is here an opportunity because of an increased profit from innovative activities? Or is the expected decline in innovation logically, since one would expect there to be less demand for products and worse investment opportunities during an economic crisis? The answers to these questions have important firm/government policy implications, for should the exertion of innovation effort during times of economic crisis either be encouraged or discouraged?

The topic of this thesis, the influence of economic crises on the relationship between innovation effort and productivity has not been researched directly before: the existing literature only touches this subject, as it has been approached in entirely different set-ups: The closest studies in terms of models describe the influence of undertaking innovation before an economic crisis (one observation) on either the performance or survival odds during an economic crisis (again, only one observation), which is found to be positive (Teplykh, 2014; Sidorkin & Srholec, 2013; and Antonioli, Bianchi, Mazzanti, Montresor & Pini, 2011). In other words, the existing literature only researches the impact of innovation effort before an economic crisis on performance/survival odds during an economic crisis. The effect of conducting innovative activities during an economic crisis, however, is not addressed. Since during economic crises, financial constraints are tightened, the division of resources becomes more critical. The choice to change the innovation budget is faced by many firms then. This thesis addresses the question whether it is more, less or as profitable as when there is no economic crisis, to exert innovation effort during an economic crisis.

More specifically, this thesis measures the influence of the depth of economic crises on the relationship between innovation effort and productivity before, during and after economic crises: a possible change (and its magnitude) in the relationship between innovation effort and productivity during and shortly after times of economic crisis is studied instead of the impact of conducting innovative activities during a specific before-crisis time on the performance/survival odds during a crisis, without determining the possible added value of exerting innovation effort during economic crises, as has been done in the existing literature. Also, the impacts of various depths of economic crises are not taken into account either in the existing literature, while they are in this thesis. Furthermore, a more general sample in terms of country and time period selection (including multiple economic crises) is used in this thesis, compared to the existing studies.

The background, the importance and the gap have now been determined. All of this leads to the following research question:

“What is the influence of economic crises on the relationship between innovation effort and productivity?”

This research question addresses three parts of the influence of economic crises on productivity and its relationship with innovation effort. The direct, mediating and moderating influence of economic crises is studied. A more comprehensive explanation of this research structure is given below, in the theoretical part of this thesis.

The topic is first discussed theoretically, where the expectations and, subsequently, hypotheses are determined. Then, the specifications of the data and the empirical tests for the hypotheses are explained. After that, the results are shown and their reliability discussed. Based on both the theoretical framework and the results, conclusions and their implications are drawn. Finally, the limitations of this study will be discussed.

Theoretical framework

In this section, the existing research and other theory behind economic crises and their (in)direct impact on productivity through innovation effort will be discussed. First, the expected impact of innovation effort on productivity in times without economic crisis will be highlighted. Then, the theorized (in)direct impact of economic crises on this relationship between innovation effort and productivity will be discussed.

Productivity, the rate at which goods or services (or rather their value) are produced, is one of the most important determinants of economic performance. It shows the efficiency with which the inputs, capital and labor, are converted into (relatively) finished products or services. The rate at which value (products and services) is created per amount input of capital and labor can, according to the basic Solow growth model (Solow, 1957), be improved upon by technological progress:

$$Q(t) = A_K(t)K(t)^{\alpha}A_L(t)L(t)^{1-\alpha}$$

With Q being the output (value), A being the technological level of capital (K) and labor (L). The improvement of the rate of value creation per amount of capital and labor is defined as total factor productivity (TFP) growth, a quantity change in value added output divided by a quantity change in combined labor and capital input; the Solow residual. This residual is mostly attributed to technological progress, of which the impact of the input (the part that is controlled by the firms/countries) is studied in this thesis: innovation effort. This is the effort put into creating technological change: R&D expenditure, (relative) numbers of employees working in R&D, et cetera, to create product/process developments.

Impact innovation on productivity

When there is no economic crisis, the relationship between innovation effort and productivity is expected to be positive in the sense that technological progress helps to create more value, more efficiency and/or lower production costs.

General Impact

A product or service represents value to a customer. This value is created using the already mentioned inputs, capital and labor. Between the start of a production (raw materials) or service process and the end of it, the delivery to the customer, is the chain of actions all adding value to the possibly already produced semi-finished product or service: the value chain. This value chain can be completed within one firm; it can also be split among several firms. Each firm adds its own value to the product or service using its inputs of capital and labor. The rate at which this value is added in terms of input is the productivity of the firm, as already mentioned above. This rate can be improved upon by technological progress/innovation: a development of a new or improved product or production process. This way, either the created value per amount of input capital and labor grows (value advantage) or the needed amount of input capital and/or labor to create the same amount of value decreases (cost advantage). In both instances, the amount of created value per input amount of capital and labor increases, leading to an advantage: the productivity is increased. This advantage can, when large enough, even change the market structure (temporarily) to a monopoly, making the innovator able to demand monopoly prices for its products, achieve monopoly profits and therefore enjoy the complete reward of the gained advantage through innovation. This expected positive impact of innovation effort on productivity has been confirmed econometrically by Therrien & Hanel (2011) and Mention & Asikainen (2012), which finds that Luxembourgish service sector firms with higher innovation output sales (sales of new and improved products per employee) achieve higher labor productivity during the 2002-2004 sample period.

Likewise, the argument can be made that the input of innovation is important for the production process as a way to maximize capacity use and, therefore, labor productivity: innovation is described as being the guarantee of perpetuation and improvement of productive cycles, as well as the improvement of the work of human resources: innovation is found to enable the full use of the input capacity (Vieira, Neira & Vázquez, 2011).

Mechanisms

In the above paragraphs, the basic relationship between innovation effort and productivity has been discussed. As is clear from all of the above, this relationship is, in general, expected to be positive. Mechanisms in this relationship have a positive or negative impact as well, however. For example, productivity is found to be positively impacted by one of the two forms of innovation effort: product innovation effort. The impact of the other form, process innovation effort, is found to be more ambiguous and short-term (Hall, Lotti & Mairesse, 2009; Pianta &

Vaona, 2007; Hall, 2011; Bogliacino & Pianta, 2010; Lee & Kang, 2007 and Parisi, Schiantarelli & Sembenelli, 2006). This is explained, however, by Masso & Vahter (2008), which finds that macroeconomic conditions just favor one form of innovation over the other during certain periods: a need for new export markets induces product innovation, while growing labor costs make it more important to reduce production costs, causing process innovation to be more important.

The positive impact of innovation on productivity can be found at the country level as well. The impact of innovation on productivity is shown to be positive in less-developed countries, since less developed countries have both much room for technological improvement and are able to rely on knowledge already established in developed countries, by Dabla-Norris, Kersting & Verdier (2012). This makes the undertaking of innovation not very resource-intensive: less-developed countries are able to generate a productivity improvement at a low cost of innovation effort.

As can be seen from the arguments discussed above, the relationship between innovation effort and productivity is expected to be positive.

Influence economic crises

The impact of economic crises on productivity is, potentially, threefold (figure 1): directly (path 1), mediating through innovation effort (paths 2 & 3) and moderating via an impact on the relationship between innovation effort and productivity (path 4). As motivated earlier, this study is mainly focused on the last of those effects, although the other two will be identified as well; in order to show the complete picture of impact in this region of economic theory and practice.

Paths 2 and 3, the mediating indirect impact of economic crises on productivity through innovation effort, have already been discussed partly: the effect of innovation effort on productivity, path 3, has been treated above. The other step, path 2, will be discussed below.

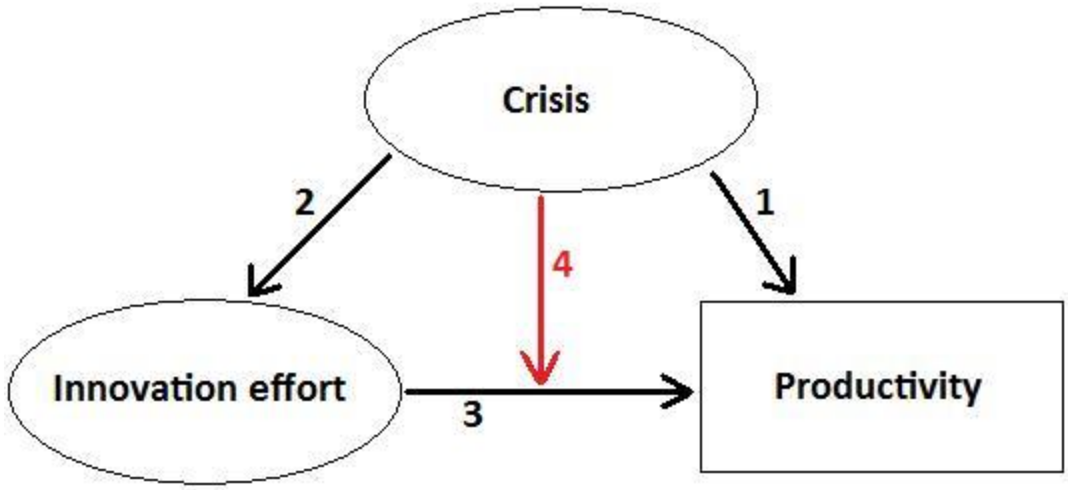

Figure 1.The subject of this thesis shown schematically: the (in)direct impacts of the variables of interest.

Impact economic crises on innovation effort

Along the lines of figure 1, the expected impact of economic crises on innovation effort (path 2) will be discussed here. This theoretical discussion will be based mostly on existing literature.

As mentioned before, it has been found that the introduction of innovations is significantly related to financial constraints: in times of crisis, when the lack of cash flow is more urgent for most companies, this notion would predict a decline in the number of introductions of innovations. The influence of tightening financial constraints (cash flow & credit) possibly has an impact in one of the following two ways as well: it can either cause a firm to be more risk-averse and conservative and therefore decrease (innovative) investment, or it can cause a firm to become more risk-taking and view investment as a "last chance" at success/survival (Parisi, Schiantarelli & Sembenelli, 2006).

Similarly, Arslan, Florackis & Ozkan (2006) finds that constrained firms exhibit greater investment sensitivities than unconstrained firms. This is confirmed by showing that access to credit (credit lines) causes firms to invest more: in times of financial crisis, firms are often forced to choose between saving and investing. Credit lines thus ease the impact of financial crises on corporate spending (Campello, Giambona, Graham & Harvey, 2012). Similarly, firms with access to public funds were less likely to stop innovation investments and younger firms as well as firms that supply foreign multinationals were more likely to cease innovating efforts (Paunov, 2012). In line with these findings are the results that show that the debt crisis of 1982 played a major role in the decrease of domestic investment in lesser developed countries, where the low financial development level impacts the exerted innovation effort negatively anyway: on average, even fewer investments were made as a result of the crisis. Also, structural shifts are found in the investment equation during and after the crisis: the debt crisis changed the sensitivity of investment to economic shocks, since firms became relatively more reliant on domestic financial sources because of the decreased international willingness for financial transactions during and shortly after the crisis (Rockerbie, 1994). On average, the 2008 economic crisis is also found to have reduced short-term willingness of firms to exert innovation effort. However, this is found not to be the case for all firms: company drivers of innovation investment before and during the crisis are compared. It is found that the 2008 crisis caused a concentration of innovation effort: mostly either new and fast growing firms or firms that were already highly innovative before the crisis exerted innovation effort during the crisis. The firms that were focused on explorative innovation, new product and market development, are the ones that coped best with the crisis (Archibugi, Filippetti & Frenz, 2013).

Based on the pieces of theory above, it is expected that economic crises cause a decrease in innovation effort. Also, as established earlier, innovation effort is expected to have a positive influence on productivity (TFP). Combined, (arrows 2 and 3 in figure 1) it follows that:

Hypothesis 1: Economic crises have a negative mediating impact on productivity (TFP), through a direct negative impact on innovation effort.

Direct impact economic crises on productivity

This theoretical section treats the direct impact of economic crises on productivity (path 1 in figure 1). This is done by reviewing existing theory, accompanied by own insights.

In times of adverse economic conditions, productivity is expected to go down because of resource misallocation, input underutilization, poor financial intermediation and not exclusively focusing on short-term input needs. Evidence for the first of these causes of decreased productivity in times of economic crisis is given by Oberfield (2013). In this study, it is shown that total factor productivity decreases during financial crises. It is found that this impact can be attributed to falling technological progress and resource misallocation. Poor between-industry allocation efficiency is discovered to have had a major impact on the reduction in TFP in the Chilean manufacturing sector in 1982. Industries that are more dependent on domestic demand are shown to have experienced larger declines in TFP, mostly because of large adjustment costs and underutilization of inputs. Especially reduced capital utilization played a large role in the decline of TFP in times of financial crisis. Poor resource allocation efficiency as a cause of a decreased productivity in times of economic crises is confirmed by the finding that both productivity and other welfare indicators decrease during economic crises, due to poor allocation of resources across divisions. This is argued to be caused by poor efficiency in financial intermediation in times of economic crisis, leading to deterioration in the working of labor markets and intermediate input markets (Sandleris & Wright, 2011).

In line with Oberfield (2013), it can be argued that during economic crises, there is less demand for products and services, causing firms to decrease their production. Still, because firing and rehiring of employees is expensive, firms may decide to keep more workers in service than short-term optimally. This way, by definition, the output per employee working hour declines: less labor productivity. For capital productivity, it works the same way: in times of economic crisis, firms decide to decrease production, since demand is down. However, unless all production capital is rented or borrowed, this means that there is going to be capital underutilization. By definition, the output per amount of capital declines: less capital productivity.

All of the studies and inferences above lead to the expectation of economic crisis to impact productivity negatively.

Hypothesis 2: Economic crises have a negative direct impact on productivity (TFP).

Moderating impact economic crises on relationship innovation and productivity

In this section, existing scientific papers that are close to this thesis' main subject, the influence of economic crises on the relationship between innovation and productivity (path 4 in figure 1), are reviewed, supplemented by general theory and own insights. The relationship between innovation effort and productivity is, as explained earlier, expected to be positive. However, during economic crises, this relationship is possibly different: the purpose of this section is to discuss whether this relationship between innovation effort and productivity is expected to stay the same or change, either positively or negatively. On the basis of that, a conclusion can be drawn whether it is expected to be rewarding to exert (more) innovation effort during times of economic crisis.

Economic crises are generally considered to be a bad thing; a basic market demand expectations argument can be made for economic crises having a negative impact on the relationship between innovation effort and productivity. In times of economic crisis, financial resources wear thin, causing the demand for products and services to go down. For most economic sectors, this means that an innovation will be less profitable than when there is no economic crisis, when there are more sales. This means that the innovation costs will be recouped more difficultly, since it can be spread over less products sold, with those products becoming worth less in turn as well: a lower demand forces a lower sale price. Thus, productivity as a result of innovation is generally expected to go down compared to when there is no economic crisis.

However, this negative impact of economic crises on the relationship between innovation effort and productivity is not necessarily the case for innovative firms, as already mentioned before. Following from innovation and productivity numbers for two separate time periods, 2005-2007 and 2009-2011 (before- and after-crisis periods), it is shown by Teplykh (2014) that the 2008 economic crisis possibly changed the transformation of corporate resources into economic benefit. More specifically, it is found that innovation activity is a survival factor during the downturn. The reasons for this are explained to lie in the Schumpeterian ideas of creative accumulation and creative destruction: firms use innovations either as competitive advantages against (upcoming) entrants and/or as opportunities to displace older, less effective, firms. The results of Teplykh (2014) confirm the above mentioned expectation that a higher R&D intensity just before a crisis is more rewarding than when there is no economic crisis in the nearby future, in terms of its impact on productivity.

The same conclusions are drawn by Sidorkin & Srholec (2013), which too shows that the innovativeness of a firm was a major factor affecting the odds of survival during the recent economic crisis. The results of this research indicate that a 10 percentage points increase of the share of sales accounted by products or services introduced over three years before the economic crisis broke out is associated with an estimated 1.8 percentage points decrease of the likelihood of the firm declaring bankruptcy thereafter. Since about 5 percent of the firms declared bankruptcy, innovation appears to make a big difference in the survival odds of firms during the times of crisis. Again referring to Schumpeter (1943), it is argued that competing through innovation “strikes not at the margins of the profits and the outputs of the existing firms but at their foundations and their very lives.” Arguably, this has always been the case, but the times of major crises, when the evolutionary struggle moves fast forward, magnify this effect.

The increased competitive advantage of firm innovativeness in times of economic crisis is confirmed further by Antonioli, Bianchi, Mazzanti, Montresor & Pini (2011), which focuses on the lagged performance of (pre-crisis) innovative Italian manufacturing firms: labor productivity, turnover, profit and employment. This study too connects firm’s actions before economic crisis times to firm performance during those. The results of this study suggest a strong positive relationship between past innovative activities and the capacity to react to the challenges brought by economic crises, mostly caused by firms’ characteristics (size, innovation history, industrial relations, et cetera.). On the other hand, firms involved in innovative effort in the moment the crisis burst were financially more vulnerable, and crowded out more often as a result of it. The main conclusion is that the exertion of innovation effort during/just before crisis times may seriously endanger short-term results, but enhance long-term results, after the end of the crisis.

Additionally, a limited ideas market argument for the expectation of a positive impact of economic crisis on the relationship between innovation effort and productivity can be given: in times of economic crisis, less innovation effort is exerted in general. This leaves more space for companies to innovate and thus gain sustained competitive advantages, since there is less innovative competition for every possible innovation, although these are possibly less profitable in the short term because of the presence of the economic crisis. Still, more (highly) profitable innovations per firm are left for firms that keep innovating during times of economic crisis. One has to keep in mind though, that if more firms try to profit from above notice, the advantage disappears.

In sum, innovation effort in economic crisis times can seriously threaten short-term results, even survival, but it can also lead to a (sustained) competitive advantage, making the company more successful in the short as well as the long term. The positive impact of innovation on productivity is, by the mentioned existing studies, found to be important, probably even more productively profitable in times of economic crisis than when there is no economic crisis.

Hypothesis 3: Economic crises have a positive moderating impact on the relationship between innovation effort and productivity (TFP).

Data & Methodology

In this section, the specifications of the empirical research of this study are discussed. First, the data and its sources are highlighted. Then, the variables used in the models are discussed. After that, the research method will be explained and the full models shown.

Data

The data for all but one of the variables used in this study is from the World Bank national indicator database. The World Bank Group consists of five organizations, linked to international credit and investment, public as well as private. The database itself, the World Development Indicators (WDI), is the primary World Bank collection of development indicators, compiled from officially recognized international sources. It presents the most current and accurate global development data available, and includes national, regional and global estimates.

The data for the main dependent variable of interest, total factor productivity growth, is from a different source: the Total Economy Database™ (TED) by The Conference Board. This database consists of annual data covering national indicator variable data for 123 countries in the world. TED was originally developed by the University of Groningen in the early 1990s. As of 2007, the database was transferred from to The Conference Board. In January 2010, the database was extended with a module on sources of growth, including total factor productivity. This world economy productivity module was created by Dale Jorgenson and Khuong Vu of Harvard University.

The Conference Board is a global, independent business membership and research association working in the public interest. Founded in 1916, The Conference Board is an objective, independent source of economic and business knowledge. They conduct research and convene business leaders in forums large and small, public and private. The Conference Board works within and across three main subject areas: Corporate Leadership, Economy & Business Environment and Human Capital.

The combined panel data sample used in this paper is country-level (117 countries), consisting of annual observations for the time period 1990-2013. The data sample is somewhat unbalanced, since there are less available observations for less-developed countries, compared to developed countries.

Summary statistics of the data used are shown below (table 1). Correlation matrices of this dataset can be found in Appendix A.1 and A.2. Possible problems, and the corresponding solutions, with the data are discussed below, in the results reliability section.

	mean	sd	min	max
Total Factor Productivity growth (%)	0.75	4.55	-97.20	42.28
Research and development expenditure (% of GDP)	1.07	0.96	0.01	4.84
GDP growth (3-year average, %)	3.50	4.45	-31.77	28.65
School enrollment, tertiary (% gross)	33.79	23.70	0.30	97.09
Trade openness (imports/GDP + exports/GDP)	82.60	49.93	10.83	444.10
Internet users (per 100 people)	19.77	25.82	0.00	96.00
Energy use (kt of oil equivalent) growth (%)	0.02	0.09	-0.70	2.30
Domestic credit provided by banking sector (% of GDP)	67.58	57.13	-19.14	347.34
Foreign direct investment, net inflows (BoP, current US$)	8.34e+09	2.73e+10	-2.83e+10	3.40e+11
Observations	2729			

Table 1. Descriptive statistics of the variables used in this research. Variables of both models used in this study are shown, the variable content of the models is explained below.

Variables

The influence of economic crises on innovation and the influence of economic crises on the relationship between innovation effort and productivity is researched by using mostly combined existing models for explaining the relationship between innovation and productivity: models from the already reviewed literature are combined and completed, as much as possible in terms of data availability. Also, a new variable for the measurement of economic crises is added. Such a variable is ideally of a continuous nature, in order to measure the magnitude of the influence: GDP growth. Since GDP growth is the inverted proxy of a bad economic situation, the estimated results for this coefficient have to be interpreted inversely. The 3-year average of this variable is taken, in order to ensure the actual measurement of a crisis, not just short-term fluctuations. This crisis measurement variable identifies the impact of economic crises on innovation effort and on the relationship between innovation effort and productivity more extensively than the one used most often (dummy variable) in the existing literature.

Productivity model variables

The first, and most important, model of this thesis is the productivity model. As is already partly clear from the name, the model's dependent variable is productivity growth (TFP growth) this variable is defined as a quantity change in value added output divided by a quantity change in combined labor and capital input. It is also known as the Solow residual. It is mostly attributed to technological progress. The independent variables of interest in this model are relative R&D investment (% of GDP), a proxy for innovation effort, and average (3 year) GDP growth, an inverse measurement of the presence and the severity of economic crises.

Since, as will be explained later, a fixed effects method is used to test the hypotheses, only non-fixed country characteristics influences have to be controlled for. More specifically, mostly using the existing models/theory, four non-fixed country specific influences are controlled for. First, the national education level is controlled for, since more human capital would probably increase the rate of growth of productivity significantly. Education level is proxied for by tertiary school enrollment, showing secondary school completion, tertiary school ambition and basic knowledge. Secondly, trade openness is controlled for, since it influences (international) competition and innovative spillover effects. Trade openness is defined by total relative trade (national imports + exports, % of GDP). A third variable influencing productivity other than economic crises through innovation effort is the level of development in digital infrastructure. This variable has an influence though an increase in speed of data and knowledge transfers, knowledge spillovers even. The main digital infrastructure is the internet, a network good. Therefore, the level of development of the digital infrastructure is probably proxied well by the national percentage users of internet. Also, there is a high correlation between digital and physical infrastructure, making digital infrastructure a good proxy to control for an increased productivity as possibly caused by a high physical infrastructure level as well. A fourth interfering influence would be the growth of energy use: an increased amount of capital, on average, increases the productivity of the labor that uses it. The use of energy shows how much of that capital is actually used. Especially in times of economic crisis, when there is a tendency to underuse facilities, this is an important correcting variable.

Beside fixed and non-fixed country characteristics, fixed time characteristics have to be controlled for as well. This is done here by the use of time dummies. These year fixed effects represent the influences that are general/worldwide. Global changes, a shift of production standards, a shift in raw material prices and other worldwide influences have a probable influence on productivity growth and are thus controlled for by this variable.

Innovation effort model variables

The second model of this thesis is the innovation effort model. The dependent variable of this model is innovation effort, one of the independent variables of interest in the previous model. Again, it is proxied for by the relative R&D investment (% of GDP). The independent variable of interest in this model is the same as in the previous model: average (3 year) GDP growth is used as an inverse measurement of the presence and the severity of economic crises.

Since in this model too, a fixed effects method is employed, only non-fixed country characteristics influences have to be controlled for. Similar to the previous model, variables are mostly selected from the existing literature. In this model, five non-fixed country characteristics control variables are used. First, the national education level influences innovation effort indirectly: human capital increases the profit from innovation effort, since the time/money is used more efficiently. Therefore, more innovation effort will be exerted. Again, education level is proxied for by tertiary school enrollment, showing secondary school completion, tertiary school ambition and basic knowledge. Secondly, trade openness influences innovation effort twofold: an increased trade openness increases (international) competition. To remain profitable, innovation is needed and innovation effort increased. On the other hand, increased trade openness increases the probability of spillover effects. This usually motivates to underinvest in innovation. Trade openness is again measured by total relative trade (national imports + exports, % of GDP). Thirdly, the level of development of digital infrastructure influences the effort put into innovation in two opposite directions: while an increase in the development level of digital infrastructure increases the probability of spillover effects, generally decreasing the effort exerted for innovation, it also increases the possibilities for knowledge sharing, making additional innovation effort more rewarding. The level of development of digital infrastructure is again proxied for by the percentage internet users. Fourthly, the availability of debt influences innovation effort positively, especially in times of economic crisis. The used proxy for this variable is the relative domestic credit provided by the banking sector (% of GDP). Similarly, the net foreign direct investment (FDI) inflow determines the available resources for innovation, influencing the innovation effort positively (again, especially during times of economic crisis) as well.

Beside fixed and non-fixed country characteristics, fixed time characteristics have to be controlled for as well. Again, this is done here by the use of time dummies. These year fixed effects represent the influences that are general/worldwide. Global changes, a shift of the technological frontier (a technological shock) and other worldwide influences have a probable influence on the effort exerted for innovation and are thus controlled for by this variable.

Method

As already mentioned, the method chosen to test the hypotheses is a fixed effects method (country fixed effects) with manually added time fixed effects. This method was the most logical one, based on the chosen measurement intentions (measure impact over time), the variables (continuous variables) and the available data (panel data).

The only real choice that had to be made was the one between the use of either a fixed effects model or a random effects model. The fixed effects model exploits the within variation of the data, the variation within countries over time, while the random effects model also uses the between variation (cross-section) of the data. The random effects model, however, is only valid if both components of the error term (the fixed part and the error part) are uncorrelated with all regressors. To make a choice between the two methods, the Hausman test is used. The Hausman test checks the hypothesis that the output of the fixed effects and random effects models is similar. If it is, the random effects method should be used, since it is more efficient. However, the output turned out to be dissimilar, making fixed effects the only reliable choice.

In sum, the two regression models are as follows:

$$TFP\ growth_{it} = \alpha_i + \beta_1 R\&D\ expenditure_{it} + \beta_2 GDP\ growth_{it} + \beta_3 R\&D\ expenditure_{it} * GDP\ growth_{it} + \beta_4 tertiary\ enrollment_{it} + \beta_5 trade\ openness_{it} + \beta_6 internet\ users_{it} + \beta_7 energy_{use\,it} + \sum_{t=1990}^{2013} \delta_t\ year_t + u_{it}$$

$$R\&D\ expenditure_{it} = \alpha_i + \beta_1 GDP\ growth_{it} + \beta_2 tertiary\ enrollment_{it} + \beta_3 trade\ openness_{it} + \beta_4 internet\ users_{it} + \beta_5 domestic\ credit\ banks_{it} + \beta_6 FDI\ inflow_{it} + \sum_{t=1990}^{2013} \delta_t\ year_t + u_{it}$$

Where the subscripts i and t show variables to vary per country and over time, respectively.

Results

In this section, the results of the empirical tests are shown and explained with respect to the hypotheses. Also, the reliability and the robustness of the results are discussed.

Regression results

The regression results of the innovation effort model, estimating the first half of the result for determining the validity of hypothesis 1 (Economic crises have a negative mediating impact on productivity, through a direct negative impact on innovation effort), are displayed in table 2.

	(1) Research and development expenditure (% of GDP, ln)	
(t-1) GDP growth (3-year average, %)	-0.011**	(0.004)
Tertiary enrollment rate (%, ln)	0.288**	(0.064)
Trade openness (imports/GDP + exports/GDP, ln)	-0.028	(0.087)
Internet users (per 100 people, ln)	-0.034**	(0.008)
Domestic credit provided by banking sector (% of GDP, ln)	0.011	(0.034)
Foreign direct investment, net inflows (BoP, current US$, ln)	0.008	(0.010)
Time Fixed Effects	Yes	
Observations	829	

Standard errors in parentheses, + p<.10, * p<.05, ** p<.01

Table 2. The results from the innovation effort regression model, containing one independent variable of interest (GDP growth as an inverted proxy for economic crises) and 6 control variables (including time fixed effects).

In table 2, it can be seen that past 3-year average GDP growth is estimated to have a significant negative influence on relative R&D expenditure: a percentage point increase in 3-year average GDP growth is estimated to cause a 0.01% decrease in relative R&D expenditure a year later, ceteris paribus. An economic crisis, therefore, is estimated to cause a significant increase in relative R&D expenditure a year later. This disproves the first part of hypothesis 1, in which economic crises are expected to cause a decrease in R&D expenditure. This, in turn, is expected to cause a decrease in Total Factor Productivity. The second part of the first hypothesis is found a result for below.

The regression results of the productivity model, estimating (the second half of) the results for determining the validity of hypotheses 1 (Economic crises have a negative mediating impact on productivity through innovation effort), 2 (Economic crises have a negative direct impact on productivity) and 3 (Economic crises have a positive moderating impact on the relationship between innovation effort and productivity), are displayed in table 3.

In table 3, it can be seen that past relative R&D expenditure is estimated to have a significant positive influence on Total Factor Productivity growth: a 1% increase of relative R&D expenditure is estimated to cause a 1.87 percentage points increase in Total Factor Productivity growth a year later, ceteris paribus. This proves the second part of the first hypothesis right, in which an increased R&D expenditure is expected to cause an increase in Total Factor Productivity. In total, though, the first hypothesis, which states that economic crises have a negative mediating impact on Total Factor Productivity, through a direct negative impact on innovation effort, is shown to be wrong. This is because the first part of the hypothesis was disproven earlier.

	(1) Total Factor Productivity growth (%)	
(t-1) Research and development expenditure (% of GDP, ln)	1.868**	(0.482)
(t-1) GDP growth (3-year average, %)	0.150*	(0.075)
(t-1) interaction R&D exp. (% of GDP, ln) & GDP growth (3-year average, %)	-0.191**	(0.064)
Tertiary enrollment rate (%, ln)	0.692	(0.925)
Trade openness (imports/GDP + exports/GDP, ln)	5.865**	(1.844)
Internet users (per 100 people, ln)	0.086	(0.277)
Energy use (kt of oil equivalent) growth (%)	4.002	(2.569)
Time Fixed Effects	Yes	
Observations	803	
R^2	0.403	

Standard errors in parentheses, + p<.10, * p<.05, ** p<.01

Table 3. The results from the productivity regression model, containing three independent variables of interest (R&D expenditure as a proxy for innovation effort, GDP growth as an inverted proxy for economic crises and an interaction of both) and 5 control variables (including time fixed effects).

Past 3-year average GDP growth is estimated to have a significant positive influence on Total Factor Productivity growth: a percentage point increase in 3-year average GDP growth is estimated to cause a 0.15 percentage points increase in Total Factor Productivity growth a year later, ceteris paribus. An economic crisis (proxied for by a decreased average GDP growth), therefore, is estimated to cause a significant direct decrease in Total Factor Productivity a year later. This confirms the second hypothesis, which states that economic crises have a direct negative impact on Total Factor Productivity.

The impact of past 3-year average GDP growth on the relationship between relative R&D expenditure and Total Factor Productivity is estimated to be significantly negative: a percentage point increase in 3-year average GDP growth is estimated to cause a relative decrease of 0.19 percentage points in the estimated impact of R&D expenditure on Total Factor Productivity growth a year later, ceteris paribus. An economic crisis, therefore, is estimated to cause a significantly positive change in the relationship between R&D expenditure and Total Factor Productivity a year later. This confirms the third hypothesis, which states that economic crises have a positive moderating impact on the relationship between innovation effort and Total Factor productivity.

Reliability results

In this part, the reliability of the results is discussed. A possible reverse causality problem is highlighted and statistical tests of the data and the models are discussed. Also, the robustness of the results is checked.

Possible reverse causality

The 'normal' expected relationship between innovation and productivity is as follows: technological development causes a higher return to labor/capital because of, for example, the automation or optimization of tasks. However, it is of course also possible that higher levels of productivity can lead to more innovation effort through capital accumulation. This possible reverse causal effect, which is also described in the existing literature, is controlled for by using a time lagged measured relationship of innovation effort with productivity. This time lag is one year, as is commonly used in the existing literature. An important side note is that the use of a lagged innovation effort variable is also theoretically sound, since there is usually a little bit of time between the exertion of innovation effort and the actual implementation and, subsequently, improved productivity.

Regarding the second model, the innovation effort one, a similar reverse causality reasoning can be made: although it is probable that economic crises have an impact on innovation (effort), the reverse is found to be possibly true as well by Gibson (2010) and

Freeman & Perez (1988). Competition is found to lead to (financial) innovation effort, leading to unsustainable debt build-ups as the risk of using innovative financial instruments is consistently underestimated and underpriced. Sooner or later, this innovation debt bubble is expected to burst. Also, firms might, because of a high level of competition, resort to unwarranted innovation effort exertion to create a competitive advantage. According to general competition theory, this innovation effort has to be financed mainly by credit; firms in a competitive environment are expected not to have large amounts of profit available to reinvest. In times of perceived safety, very possibly coupled to the available (innovative) products of the financial markets, this too can lead to an underestimation and underpricing of the risks of innovation, causing the innovation credit bubble to become larger, until it bursts. Thirdly, it is argued that the widespread diffusion of new technology throughout the economic system is not just a matter of incremental improvements, but a major change in all economic sectors. These transition shocks are explained to cause structural crises: supply/demand mismatch of various economic factors and instability of investment behavior. These possible reverse causal effects are controlled for by using a time lagged measured relationship of economic crises with innovation effort. The used time lag is, again, one year.

Tests

To further ensure the reliability of the results of the regression models, various statistical reliability tests were conducted.

For the productivity model, the joint dummy test confirms that time fixed effects are needed. The "Breusch-Pagan/Cook-Weisberg test for heteroskedasticity" shows that there is no heteroskedasticity issue. The "Wooldridge test for autocorrelation in panel data" shows no first order autocorrelation. The Variance Inflation Factor (VIF) test shows no multicolinearity risk. Furthermore, the variables that show worrisome correlations (appendix A.1) are tested for causing bias in the model separately (appendix B.1). No troubling results are found.

For the innovation effort model, the joint dummy test confirms that time fixed effects are needed. The "Breusch-Pagan/Cook-Weisberg test for heteroskedasticity" shows that there is a heteroskedasticity issue. Also, the "Wooldridge test for autocorrelation in panel data" shows first order autocorrelation. For those reasons, the fixed effects regression is performed with Driscoll-Kraay standard errors, solving both problems simultaneously. The VIF test shows no multicolinearity risk. Furthermore, the variables that show worrisome correlations (appendix A.2) are tested for causing bias in the model separately (appendix B.2). No troubling results are found.

To test the estimated indirect effect of economic crises on productivity through innovation effort, a multi-level mediator test (Krull & MacKinnon, 2001) is performed (appendix C). The results from this test confirm the direction and significance of the estimations of the models of this thesis regarding the impact of innovation effort on productivity. The influence of economic crises on innovation effort is estimated by the test not to be significant, though.

Robustness results

The robustness of the estimated results is checked for by using alternative (in)dependent variables in the models described above. These alternative variables have also been used in the existing literature. For the first model, the productivity model, the alternative variables are as follows: Real GDP growth per person employed (%) (dependent variable, productivity, data from www.worldcompetitiveness.com), the relative number of technicians in R&D (independent variable of interest, innovation effort) and an economic crisis dummy (independent variable of interest, economic situation). For the second model, the innovation effort model, the alternative variables are similar: the relative number of technicians in R&D (dependent variable, innovation effort) and an economic crisis dummy (independent variable of interest, economic situation).

The results of these alternative variable models (appendix C.1 & C.2) confirm the sign and significance of most of the estimations of the original models. For the productivity model, however, the impact of increased innovation effort on productivity is estimated not to be significantly different from 0. For the innovation effort model, the impact of an economic crisis on productivity is estimated not to be significantly different from 0. These results, however, can probably be attributed to a relative lack of observations, time-wise as well as cross-section, compared to the data used in the original model.

To ensure the results of this study are valid over the entire sample period, various subsamples of the chosen period were used to run the regression model. No major differences were found.

Discussion & Conclusions

The purpose of this thesis is to test the influence of economic crises on the relationship between innovation effort and productivity. To do this, the hypotheses tested in the previous section are as follows:

Hypothesis 1: Economic crises have a negative mediating impact on productivity (TFP), through a direct negative impact on innovation effort.

Hypothesis 2: Economic crises have a negative direct impact on productivity (TFP).

Hypothesis 3: Economic crises have a positive moderating impact on the relationship between innovation effort and productivity (TFP).

The first hypothesis is not supported by the data analysis. The second and third hypotheses have been confirmed: economic crises were found to indirectly cause productivity to increase, through an increased level of innovation effort. Secondly, economic crises were shown to directly cause productivity to decrease. Thirdly, economic crises were found to cause an increase in the (positive) influence of innovation effort on productivity. The estimated impacts studied are displayed schematically in figure 2.

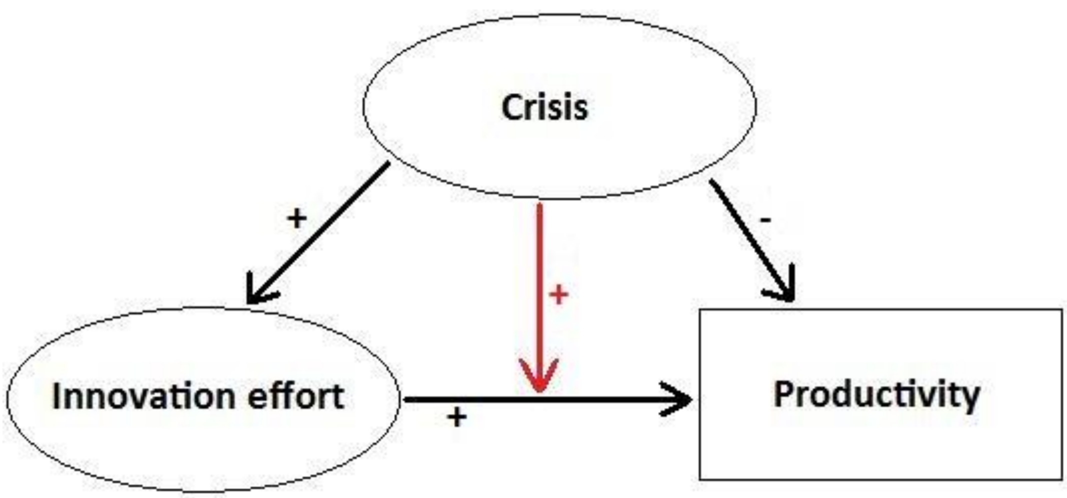

Figure 2.The results of this study shown schematically: the direct, mediating and moderating impacts of economic crises on productivity, through its relationship with innovation effort.

As can be seen from figure 2, economic crises are estimated to influence productivity negatively directly. This relationship is as expected (hypothesis 2); confirming that productivity is impacted negatively by resource misallocation, input underutilization and poor efficiency in financial intermediation during economic crises, which has also been found by Oberfield (2013) and Sandleris & Wright (2011). Also, firms are expected to keep labor and capital operational (not firing/selling in the short term) while demand goes down during economic crises. Less value is created per operational unit of input this way: productivity falls. Productivity is thus expected and estimated to fall as a direct effect of economic crises.

What was not expected is that, according to the results of the data analysis, economic crises apparently have a positive impact on productivity indirectly, through their influence on the exerted innovation effort (contrary to hypothesis 1). This indirect impact consists, as explained, of two consecutive impacts. The second one, the expected positive impact of innovation effort on productivity, was confirmed. The exertion of innovation effort is expected to have a positive effect on the amount of value a firms adds to a production/value chain, divided by the amount of production inputs: either the amount of value per product unit is increased or the amount of inputs needed to produce the same amount of value is decreased. Both effects increase productivity through the value chain. This has been found econometrically by Therrien & Hanel (2011) and Mention & Asikainen (2012). The input of innovation is expected to be important as a way to maximize capacity as well, as has also been found by Vieira, Neira & Vázquez (2011). Innovation effort is thus expected and estimated to cause an increase in productivity.

The first part of the mediating impact of economic crises on productivity, however, the expectedly negative impact of economic crises on innovation effort, was not confirmed: economic crises are expected to cause a decrease in innovation effort through a tightening of financial constraints, as has been found by Parisi, Schiantarelli & Sembenelli (2006), Arslan, Florackis & Ozkan (2006) and Campello, Giambona, Graham & Harvey (2012). Yet, economic crises are found to have caused an increase in innovation effort. This can be explained by there being a relatively high number of highly innovative firms during the researched economic crises: as mentioned in the theoretical framework, Archibugi, Filippetti & Frenz (2013) found that highly innovative firms did not decrease their innovation effort during times of economic crisis and were rewarded in the form of highly increased productivity and survival odds. If there are relatively many of such firms, the total innovation effort does not decrease much during economic crises. Moreover, if most firms were already aware of the estimated rewards of the exertion of innovation during economic crises, it might have caused them to actually increase their innovation effort.

This line of thought is seamlessly connected to the main result of this thesis: the relationship between innovation effort and productivity is estimated to be more positive in times of economic crisis (hypothesis 3). The expected result of an economic crisis is an intensified struggle for survival. In this struggle, every competitive advantage, acquired through innovation, is expected to have an even larger reward than when there is no economic crisis (Teplykh, 2014 and Sidorkin & Srholec, 2013). Also, innovative firms have been found to be more successful during economic crises due to their capacity for creativity in dealing with the challenges of an economic crisis (Antonioli, Bianchi, Mazzanti, Montresor & Pini, 2011). However, since financial constraints are tight during economic crises, firms have an increased risk of bankruptcy when exerting innovation effort: they are less able to deal with very short-term financial difficulties. It is also argued that during times of economic crisis, there is more freedom in choosing improvement technologies, since the competition for innovation is less in times of economic crisis. This argument, though, is found not to be valid since innovation effort, and therefore also innovative competition, is estimated to actually increase during economic crises. A basic market demand argument, showing that a decline in customer demand causes a decline in added production value per amount of inputs as a result of innovation, introduces a negative impact of economic crises on the relationship between innovation effort and productivity as well. The extra-positive rewards of economic crises for the exertion of innovation effort in terms of productivity are estimated to be higher than the extra-negative ones, though: during times of economic crisis, it is estimated to be even more rewarding to exert innovation effort than when there is no economic crisis, in terms of productivity.

So, economic crises turn out not to be bad exclusively: although firm productivity is estimated to decrease as a direct result of economic crises, the productivity reward of exerting innovation effort is found to be higher during an economic crisis than not during one. Firms should thus, as much as financially possible, increase their innovation effort in times of economic crisis. Also, since economic crises increase the competition to make either a profit or even just survive, firms should embrace the possibility to gain an advantage.

Public policy should therefore encourage firms to exert innovation effort because of its apparent rewards. However, it should also be taken into account that during economic crises, some firms will likely go bankrupt, even when they are able to increase their performance through the exertion of extra innovation effort. The exertion of innovation effort, mostly financial investment, causes firms to be able to repay less of their debts in case of a bankruptcy, since there are less financial buffers left. By encouraging innovation effort too much during economic crises, policy makers may therefore cause the debt repayment rate to sink below a safe level. This might cause financial institutions to permanently raise interest rates, debt conditions, et cetera: a shift in the financial system. This shift and its additional instability probably have a negative influence on the economic system as a whole, including the possibilities for the undertaking of innovation in the future.

The main result of this thesis is that the exertion of innovation effort is found to be more rewarding during economic crises than when there is no economic crisis. Firms should therefore exert more, or at least not less, innovation effort when times are tough economically. Public policy should encourage this, however moderately.

Limitations

In this section, the limitations of the conducted study are discussed. The possible problems and reliability issues of the results are shown to be mainly due to the limited data availability.

The results of this study come from econometrically researching panel data (117 countries, 1990-2013). This panel data, however, is rather unbalanced, since it contains more observations for developed countries than for less-developed countries. The found results, and the subsequent conclusions, are therefore probably valid for developed countries, but not for less-developed ones.

The sample period (1990-2013) used for this research contains observations for only the most recent crises, making the results either very applicable in the case of modern crises, or not generally valid enough to draw reliable conclusions for economic crises in general.

The data contains observations at the country level. Although fixed country characteristics are approximately taken into account, some of these characteristics might not actually be close enough to being fixed, possibly making the results unreliable.

The direct, mediating and moderating impact of economic crisis on productivity, through its relationship with innovation, are estimated at a country level. Although this makes the results valid for general evaluation, the estimations might be more practically and specifically applicable if they were at a sector/industry level. That way, both public and firm policy following from the results could be tailored to the (firms in the) concerning sector/industry.

Further research should therefore focus on collecting industry-level data, more data from less-developed countries and for a longer time period, to ensure the general validity and practical usability of the findings.

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Appendix

Appendix A.1: correlation table productivity model

	Total Factor Productivity growth (%)	(t-1) Research and development expenditure (% of GDP, ln)	(t-1) GDP growth (3-year average, %)	(t-1) interaction R&D exp. (% of GDP, ln) & GDP growth (3-year average, %)	Tertiary enrollment rate (%, ln)	Trade openness (imports/GDP + exports/GDP, ln)	Internet users (per 100 people, ln)	Energy use (kt of oil equivalent) growth (%)
	b	b	b	b	b	b	b	b
Total Factor Productivity growth (%)	1.00							
(t-1) Research and development expenditure (% of GDP, ln)	-0.11	1.00						
(t-1) GDP growth (3-year average, %)	0.38	-0.31	1.00					
(t-1) interaction R&D exp. (% of GDP, ln) & GDP growth (3-year average, %)	-0.30	0.77	-0.59	1.00				
Tertiary enrollment rate (%, ln)	-0.04	0.53	-0.16	0.39	1.00			
Trade openness (imports/GDP + exports/GDP, ln)	0.06	0.08	0.03	0.04	0.22	1.00		
Internet users (per 100 people, ln)	-0.11	0.51	0.01	0.39	0.57	0.29	1.00	
Energy use (kt of oil equivalent) growth (%)	0.33	-0.14	0.42	-0.14	-0.11	-0.00	-0.02	1.00

Appendix A.2: correlation table innovation effort model

	Research and development expenditure (% of GDP, ln)	(t-1) GDP growth (3-year average, %)	Tertiary enrollment rate (%, ln)	Trade openness (imports/GDP + exports/GDP, ln)	Internet users (per 100 people, ln)	Domestic credit provided by banking sector (% of GDP, ln)	Foreign direct investment, net inflows (BoP, current US$, ln)
	b	b	b	b	b	b	b
Research and development expenditure (% of GDP, ln)	1.00						
(t-1) GDP growth (3-year average, %)	-0.27	1.00					
Tertiary enrollment rate (%, ln)	0.53	-0.16	1.00				
Trade openness (imports/GDP + exports/GDP, ln)	0.08	0.03	0.22	1.00			
Internet users (per 100 people, ln)	0.50	0.01	0.57	0.29	1.00		
Domestic credit provided by banking sector (% of GDP, ln)	0.60	-0.19	0.55	0.14	0.44	1.00	
Foreign direct investment, net inflows (BoP, current US$, ln)	0.52	0.13	0.53	0.04	0.50	0.49	1.00

Appendix B.1: regression table productivity model multicolinearity bias test

	(1) Total Factor Productivity growth (%)	(2) Total Factor Productivity growth (%)	(3) Total Factor Productivity growth (%)	(4) Total Factor Productivity growth (%)
(t-1) Research and development expenditure (% of GDP, ln)	1.868**	1.078*	1.715**	1.807**
	(0.482)	(0.473)	(0.379)	(0.469)
(t-1) GDP growth (3-year average, %)	0.150*	0.309**	0.190**	0.157*
	(0.075)	(0.085)	(0.068)	(0.073)
(t-1) interaction R&D exp. (% of GDP, ln) & GDP growth (3-year average, %)	-0.191**		-0.146**	-0.186**
	(0.064)		(0.043)	(0.060)
Tertiary enrollment rate (%, ln)	0.692	0.224		0.766
	(0.925)	(0.848)		(0.977)
Trade openness (imports/GDP + exports/GDP, ln)	5.865**	6.021**	4.638**	5.816**
	(1.844)	(1.866)	(1.493)	(1.892)
Internet users (per 100 people, ln)	0.086	-0.129	-0.140	
	(0.277)	(0.241)	(0.231)	
Energy use (kt of oil equivalent) growth (%)	4.002	3.597	4.772*	4.048
	(2.569)	(2.891)	(2.101)	(2.562)
Time Fixed Effects	Yes	Yes	Yes	Yes
Observations	803	803	1000	807
R^2	0.403	0.387	0.382	0.403

Standard errors in parentheses
+ p<.10, * p<.05, ** p<.01

Appendix B.2: regression table innovation effort model multicolinearity bias test

	(1) Research and development expenditure (% of GDP, ln)	(2) Research and development expenditure (% of GDP, ln)	(3) Research and development expenditure (% of GDP, ln)	(4) Research and development expenditure (% of GDP, ln)	(5) Research and development expenditure (% of GDP, ln)
(t-1) GDP growth (3-year average, %)	-0.011**	-0.014*	-0.013**	-0.011**	-0.010+
	(0.004)	(0.005)	(0.004)	(0.003)	(0.005)
Tertiary enrollment rate (%, ln)	0.288**		0.247**	0.296**	0.326**
	(0.064)		(0.060)	(0.057)	(0.057)
Trade openness (imports/GDP + exports/GDP, ln)	-0.028	-0.011	0.000	-0.051	-0.023
	(0.087)	(0.069)	(0.085)	(0.084)	(0.112)
Internet users (per 100 people, ln)	-0.034**	-0.002		-0.034**	-0.041**
	(0.008)	(0.016)		(0.008)	(0.011)
Domestic credit provided by banking sector (% of GDP, ln)	0.011	-0.029	0.013		0.010
	(0.034)	(0.047)	(0.035)		(0.031)
Foreign direct investment, net inflows (BoP, current US$, ln)	0.008	-0.009	0.005	0.005	
	(0.010)	(0.012)	(0.010)	(0.010)	
Time Fixed Effects	Yes	Yes	Yes	Yes	Yes
Observations	829	997	835	846	866

Standard errors in parentheses
+ p<.10, * p<.05, ** p<.01

Appendix C: Krull & MacKinnon mediator test

```
command:  ml_mediation, dv(TFP_Growth) iv(GDP_Growth_1) mv(ln_RD_RelativeExpenditure_1) l2id(Country)
 indeff:  r(ind_eff)
 direff:  r(dir_eff)
 toteff:  r(tot_eff)
```

	Observed Coef.	Bootstrap Std. Err.	z	P>|z|	Normal-based [95% Conf.	Interval]
indeff	-.0003152	.0013859	-0.23	0.820	-.0030315	.0024011
direff	.3949329	.0504192	7.83	0.000	.296113	.4937528
toteff	.3946177	.0499739	7.90	0.000	.2966706	.4925648

Standard errors in third column, probability value in fifth column

Appendix D.1: regression table productivity model robustness results test

	(1) Real GDP growth pp employed (%)	
(t-1) Technicians in R&D (per million people, ln)	-1.273	(1.382)
(t-1) =1 if economic crisis (3-year average < 0%)	-17.873**	(4.760)
(t-1) interaction technicians in R&D (ln) & economic crisis dummy	2.372**	(0.682)
Tertiary enrollment rate (%, ln)	-5.409	(3.429)
Trade openness (imports/GDP + exports/GDP, ln)	0.445	(3.523)
Internet users (per 100 people, ln)	-3.563*	(1.415)
Energy use (kt of oil equivalent) growth (%)	9.534+	(5.395)
Time Fixed Effects	Yes	
Observations	252	
R^2	0.501	

Standard errors in parentheses
+ p<.10, * p<.05, ** p<.01

Appendix D.2: regression table innovation effort model robustness results test

	(1) Technicians in R&D (per million people, ln)	
(t-1) =1 if economic crisis (3-year average < 0%)	0.027	(0.063)
Tertiary enrollment rate (%, ln)	0.072	(0.105)
Trade openness (imports/GDP + exports/GDP, ln)	-0.178	(0.133)
Internet users (per 100 people, ln)	-0.052	(0.037)
Domestic credit provided by banking sector (% of GDP, ln)	0.061	(0.070)
Foreign direct investment, net inflows (BoP, current US$, ln)	0.001	(0.022)
Time Fixed Effects	Yes	
Observations	423	

Standard errors in parentheses
+ p<.10, * p<.05, ** p<.01